# CADMIUM

By Peter H. Kuck

Cadmium usage in secondary batteries continues to grow and now constitutes the major end use for the element. Cadmium (Cd) forms stable alloys with copper, tin, and several other nonferrous metals. When aluminum, brass, copper, and steel are coated with cadmium metal, they become much more resistant to corrosion, especially in marine and alkaline environments.

Cadmium pigments are more stable than organic coloring agents at elevated temperatures and are not easily degraded by light. Because of their excellent coloring properties, cadmium pigments are widely used in thermoplastics, ceramics, glazes, and artists' colors. Cadmium compounds are used to stabilize polyvinylchloride (PVC) and are frequently incorporated into solar cells, radiation detectors, lasers, and other electro-optical devices.

The price of cadmium metal partially recovered after falling to an all time record low of $0.451 per pound for the year 1993. Apparent U.S. demand for the metal declined substantially in the face of increasingly stringent environmental regulations and worldwide recessionary forces. The traditional markets in pigments, stabilizers, and coatings have all been contracting since the late 1980's. However, increasing amounts of cadmium have been coming into the United States in the form of nickel-cadmium (Ni-Cd) batteries.

Demand for Ni-Cd batteries has been growing worldwide because they are widely used in camcorders, laptop computers, and portable telephones. The bulk of the batteries entering the United States are made in Japan, Mexico, China, or France (in descending market share).

Most of the virgin cadmium currently being recovered is a byproduct of zinc refining. The cadmium is associated with the zinc in concentrates of sphalerite (ZnS) and related sulfide ore minerals. It is also recovered during the beneficiation and refining of some lead ores or complex copper-zinc ores.

Cadmium is considered toxic, particularly in soluble and respirable forms, and must be handled with care. Although cadmium commonly is associated with zinc, the two behave somewhat differently in biological systems.[1] Zinc is an essential element in almost all biological systems and plays important roles in metalloenzyme catalysis, metabolism, and the replication of genetic material. Cadmium, on the other hand, can adversely affect the renal and respiratory systems, depending upon exposure time and concentration, and is not readily excreted. Inhaled cadmium fumes or fine dust are much more readily absorbed than ingested cadmium. Repeated exposure to excessive levels of dust or fume can irreversibly injure the lungs, producing shortness of breath and emphysema. Dermal contact with cadmium results in negligible absorption. The International Agency for Research on Cancer (IARC) lists cadmium metal and several of its compounds as carcinogens.[2]

## Legislation and Government Programs

In April 1993, the Occupational Safety and Health Administration (OSHA) revised its cadmium exposure standards.[3] [See Code of Federal Regulations (Title 29 - Parts 1910, 1915, and 1928).] Additional corrections specific to construction sites and shipyards (Parts 1915 and 1926) were published on January 3, 1994.[4] The January document also contains important background information, including the safety data sheet for cadmium, technical guidelines for handling the metal and its compounds, and recommended medical monitoring procedures.

On March 22, 1994, the Federal Circuit Court of Appeals for the Eleventh District remanded the OSHA Cadmium Standard to OSHA, indicating that the agency had not established the technological feasibility of the standard for pigments formulators or those who incorporate cadmium pigments into plastics, ceramics, glasses, and enamels.[5] The court action was taken in response to a petition filed by the Color Pigments Manufacturers Association, Inc. (CPMA) with intervention of The Cadmium Council, Inc. The court did not accept the argument that a separate health standard was required for the cadmium pigments industry. For cadmium pigments users, the action effectively reinstated the old Permissible Exposure Limit (PEL) of 100 or 200 micrograms (µg) of cadmium per cubic meter ($m^3$) of air. Cadmium pigments manufacturers, though, must adhere to the requirements of the new OSHA standard of 5 µg/$m^3$. The cadmium pigments formulators have voluntarily agreed to limit their worker exposures to 50 µg/$m^3$, pending a settlement with OSHA on this issue.

On September 19, 1994, the U.S. Environmental Protection Agency (EPA) set final universal treatment standards for a number of wastes containing cadmium and other hazardous metals.[6] These wastes are part of a much larger group of wastes regulated under the Resource Conservation and Recovery Act (RCRA). EPA issued the new standards to eliminate confusion about the handling, treating, and disposal of wastes of different origins. The standards apply to "listed" wastes, and not to "characteristic metal" wastes, which have separate standards. Cadmium-bearing wastes falling into the "listed" category include: Wastewater treatment sludges from electroplating operations (Waste code F006); Leachate (F039); Emission control dusts and sludges associated with the production of steel in electric arc furnaces (K061); and Emission control dusts and sludges from secondary lead smelting (K069).

On February 11, 1993, EPA proposed new streamlined regulations governing the collection and management of spent Ni-Cd batteries, mercury-containing thermostats, and certain other widely generated hazardous wastes. The agency solicited additional comments from the general public on June 20, 1994, and put the regulations (40 CFR part 273) into effect on May 11, 1995.[7] The new regulations are designed to encourage environmentally-sound recycling of Ni-Cd batteries and keep them out of the municipal waste stream. No distinction is made on the basis of battery size or type of electrolyte.

The Defense Logistics Agency (DLA) continued to sell sticks and balls of cadmium metal from the National Defense Stockpile. Cadmium had been included in the stockpile since the Nation's entry into World War II. At that time, the metal was desperately needed for the protective plating of armament parts. However, in October 1992, the administration, together with the Congress, decided that the Government no longer needed the material and authorized disposal of the entire 2,871 metric tons (mt) in inventory. The ongoing sales are part of a much larger downsizing of the stockpile approved under the Defense Authorization Act of 1992 (Public Law 102-484).

DLA began offering the cadmium on March 22, 1993. Many of the bids during the initial 6 months were extremely low and often rejected. The first few sales drew criticism from producers and The Cadmium Council because bids were accepted in the $0.18 to $0.25 per pound range.[8] The unit prices being bid improved considerably during the second half of 1993, with some material being awarded at $0.43 per pound.

By the beginning of 1994, uncommitted stocks had shrunk to 5,884,710 pounds (2,669 mt). In early 1994, Congress approved DLA's request to raise the fiscal year sales limit from 500,000 pounds to 750,000 pounds. An additional 459,926 pounds (209 mt) were turned over to purchasers in 1994, leaving uncommitted stocks of 5,250,135 pounds (2,381 mt) on December 31. Total yearend stocks also included 210,060 pounds (95 mt) of committed material.

## Production

Primary cadmium was produced by only two companies: Big River Zinc Corp., Sauget, IL; and Savage River Zinc Co., Clarksville, TN. Both companies recovered cadmium as a byproduct of smelting domestic and imported zinc concentrates. The cadmium recovery facilities of ASARCO Incorporated, Denver, CO; and Zinc Corporation of America, Bartlesville, OK, were idle the entire year.

In spring 1994, Savage Resources Ltd. of Australia completed its acquisition of Jersey Minière. The acquisition was part of a broader transaction involving all the zinc mining and processing operations controlled in the United States by the giant Union Minière Group. On December 31, 1993, Savage River bought a 30% interest in Union Mines Inc., the parent of Jersey Minière. Union Minière sold the remaining 70% to the Australians 3 months later. The sale included both the Clarksville refinery and Jersey Minière's four zinc mines, which are also in Tennessee.

Domestic production data for cadmium metal and compounds are developed by the U.S. Bureau of Mines (USBM) from a voluntary survey of U.S. operations. All four present or recent producers responded to the Bureau's 1994 survey requests.

Since 1993, the International Metals Reclamation Co., Inc. (INMETCO) has been recovering test quantities of cadmium metal at its metals recovery facility in Ellwood City, PA. The facility was set up in 1978 to reclaim chromium and nickel from emission control dusts, swarf, grindings, and mill scale—all generated by the stainless steel industry. The plant later was modified to process filter cakes, plating solutions and sludges, spent Ni-Cd batteries, and a variety of other recyclable ferrous metal-bearing wastes. In 1993, INMETCO produced 22,196 mt of chromium-nickel-iron alloy from 58,000 mt of solid waste and 710,000 gallons of liquid waste. The 58,000 mt of solids included 1,900 mt of spent consumer and industrial Ni-Cd batteries.[9]

INMETCO processed even more batteries in 1994—2,417 mt with an average Cd content of 15%—generating 363 mt of secondary cadmium. The company reclaimed a similar amount of cadmium in 1994 from electric arc furnace dusts and plating sludges. Prior to 1995, the cadmium from the batteries and other wastes was recovered as a baghouse dust and shipped offsite for further processing.

In May 1994, INMETCO acquired key cadmium recovery technology from Saft Nife AB. That same month, INMETCO awarded a contract to design and construct a full-scale cadmium recovery unit at Ellwood City. This unit was to be commissioned in late 1995.

## Consumption

Apparent consumption of cadmium metal in the United States dropped 65% between 1993 and 1994. (See table 3.) The USBM does not collect actual consumption data on either cadmium metal or cadmium compounds. However, the International Cadmium Association does make annual estimates on an end use basis for the Western World. Their breakdown for 1994 was as follows: batteries, 65%; pigments, 15%; stabilizers for plastics and similar synthetic products, 10%; coatings and plating, 10%; and alloys and miscellaneous, 2%.[10]

A significant shift in the cadmium demand pattern has occurred over the last 10 years. Demand for Ni-Cd batteries has grown, while markets for other key cadmium-based products have shrunk. The markets for pigments, stabilizers, and coatings have declined steadily since 1991 when the European Union (EU) began tightening restrictions on cadmium-based products.

The incineration of plastics containing cadmium pigments and stabilizers is of greater concern in Western Europe than in the United States. Landfilling, which locks up the cadmium, is not a viable option in the Benelux countries and other parts of Europe where the population density is extremely high and geologically secure sites are limited.

New health and safety regulations in both the EU and the United States have discouraged sales of cadmium-based products to the heat stabilizer market. On January 1, 1994, Witco Corp. voluntarily stopped selling cadmium-based *solid* heat stabilizers for flexible PVC.[11] The Greenwich, CT based company also has begun phasing out sales of cadmium-based *liquid* heat stabilizers. A spokesperson for Witco said that the action was taken because of increasing regulatory pressures, negative publicity over heavy metals, and company concerns over the ultimate disposal of PVC. Witco has been encouraging its customers to switch to either barium-zinc or calcium-zinc heat stabilizers.

At least two competitors, Cookson America, Inc. and Akcros Chemicals v.o.f., have decided to continue selling cadmium-based stabilizers as long as sufficient demand exists. Both are U.S. ventures of large European chemical companies.[12]

The colorant and pigment industry has restructured almost every aspect of production in response to various new government regulations. In past years, the industry relied heavily on chromium and lead as well as cadmium. Today, the United States has fewer pigment producers and is more import dependent. The regulations also have encouraged replacement of the traditional heavy metal pigments by less attractive substitutes.

Both Engelhard Corp. and SCM Corp. have remained in the market and continue to produce cadmium sulfide. Several other companies, though, have reduced or completely phased out manufacturing of heavy metal colorants. Ciba-Geigy Corp. is a good example. The Ardsley, NY based specialty chemical producer controls about 20% of the colorant market on a dollar basis, but has not produced any heavy metal-based pigments since the 1980's.[13]

Automobile manufacturers have cut back on the use of cadmium-based pigments in car interiors. This action was taken in response to recent European restrictions. U.S. automobile manufacturers are trying to avoid producing different versions of vehicles for Europe and North America.

Replacement of key cadmium pigments by organic substitutes is not that straightforward, especially for applications that require high temperature or pressure processing. Organic substitutes are not as stable and are more difficult to work with under these conditions. In other applications, more organic pigment is needed to duplicate the color effect produced by the cadmium, driving up costs. Further substitution is becoming increasingly difficult. The alternatives still cannot match many of the properties of cadmium pigments (e.g., color brightness, opacity, heat and light stability, processability, etc.) that have made them popular for decades.

Ferro Corp. of Cleveland, OH, and Rhone-Poulenc Chimie of Paris, France were considering forming a joint venture to manufacture and market a line of cerium sulfide ($Ce_2S_3$) pigments.[14] Cerous (III) sulfide is red in color and appears to be a suitable alternative to some of the cadmium-based red pigments currently used in plastics. Several ceric (IV) salts are red-orange to yellow and conceivably could be formulated into substitute pigments. The cost competitiveness of the new substitutes still needs to be determined.

Wolverine Plating Corp. and several other plating companies in the Detroit area have stopped using cadmium and switched over entirely to zinc. The automotive industry, one of their larger customers, has dropped all of its requirements for cadmium plating because of new restrictions on the use of cadmium coatings in the EU. Most cadmium electroplaters in the United States now operate well below the OSHA action limit of 2.5 µg/m$^3$ and have not had to stop plating because of the new OSHA standard. (There have been a few exceptions—primarily companies involved in mechanical plating.)[15]

Cadmium plating is still required for applications where the surface characteristics of the coating are critical (e.g., fasteners for aircraft, electrical connectors, parachute buckles.) Cadmium coatings do not oxidize as readily as zinc coatings in marine or concentrated salt atmospheres and have lower relative coefficients of friction, making for smoother surfaces.

## Prices

Cadmium prices began rising dramatically at the beginning of 1994 and did not level off until October. The New York dealer price for metal, published by *Metals Week* for the week ending January 7, 1994, ranged from $0.40 to $0.50 per pound, in line with the 1993 average of $0.451 cents.

Prices were extremely depressed in 1993 and had been falling since 1989, when the average annual price for metal was $6.28 per pound. An all time historic low of $0.38 to $0.48 was reached on June 10, 1993. The low prices had a discouraging effect on recycling. Analysts attributed the depressed prices to a variety of causes, including the global economic slowdown, loss of markets due to environmental concerns, and the introduction of stricter Federal occupational exposure standards in 1992.

The economic outlook for cadmium changed in 1994. By the end of the first quarter, the quotation had recovered to $0.70 to $0.80 per pound and was still rising. The New York dealer price continued to climb throughout the summer and eventually reached $2.00 to $2.50 on September 29. The $2.00 to $2.50 price remained in effect until December 1. At this point, the price took a downturn and kept steadily slipping until it finally leveled off at $1.60 to $1.80 on March 30, 1995. Some analysts attributed the volatility to cutbacks in primary zinc production during 1993 and a subsequent short-term run on cadmium inventories by speculators and Ni-Cd battery manufacturers. The average annual price for 1994 was $1.131.

## Foreign Trade

Exports of cadmium metal and other cadmium products began to pick up in the second half of 1994, after falling dramatically in 1993. The bulk of the material went to China and Hong Kong.

Imports of cadmium metal have traditionally exceeded exports. This did not happen in 1994. Imports weakened and were down 22% from the previous year. The principal supplying countries, in descending order of receipts, were Canada, Belgium, Germany, and Bulgaria. Shipments from Mexico were down 95%. (See tables 5 and 6.)

## World Review

***Industry Structure.***—World refinery production of cadmium was estimated at 18,100 mt in 1994. Japan was by far the largest producer of refined cadmium products, followed by Canada and Belgium. (See table 7.)

***Capacity.***—World cadmium refining capacity for 1994 was estimated at 23,000 mt.

***International Cadmium Association.***— The European and North American cadmium associations merged to form the International Cadmium Association (ICdA). The Cadmium Council, Inc. in Reston, VA, is now both the North American office of the new association and the Ni-Cd Electric Vehicle Information Center. The headquarters of the Cadmium Association in London, England, became the European office of the new organization.

***European Union.***—In May 1994, an EU regulation took effect that severely limits the international transport of hazardous waste and related products. The regulation was issued under terms agreed upon by much of the world in the Basel Convention. The Convention goal was to strictly control exports of hazardous wastes to Third World countries that have limited waste management capabilities.

However, European refining and recycling companies, like Union Minière, were concerned because the complex legislation makes no distinction between materials being shipped for recycling and those being sent to a disposal site. The regulation has had a major impact on some of Union Minière's plants that rely on intermediate products and industrial residues for feedstocks.[16] Union Minière operates two zinc refineries with a combined capacity of 450,000 mt of zinc per year. The two refineries)one at Balen in Belgium and the other at Auby in France)produce cadmium and sulfuric acid as byproducts.

Hydrometal S.A. of Belgium has expressed similar concerns about the EU regulation. The Belgian company has a recycling plant at Liège that treats 1,000 to 1,500 mt per month of metal-bearing oxidic residues from the rest of Europe and the United States. Hydrometal claims that the regulation is making it increasingly difficult and more expensive to obtain secondary feed materials. The company uses a hydrometallurgical process to separate cadmium, cobalt, copper, lead, nickel, tin, zinc, and precious metals from one another. The cadmium is sold as sponge; the nickel, as a carbonate; and the zinc, as a sulfate.[17]

***Mexico.***— In November 1994, Matsushita Battery Industrial Co. of Japan announced that it had established a subsidiary in Tijuana to manufacture small-size Ni-Cd batteries. The new company, Matsushita Battery Industrial de Baja California SA de CV, reportedly began packing operations in April 1995. The Tijuana plant is expected to produce 16 million units in 1996 and expand to 31 million in 1997. Matsushita launched similar operations in Belgium and Indonesia in 1993.[18]

## Current Research and Technology

Recent developments in Ni-Cd battery technology were reviewed at an international conference on September 19-20, 1994, in Geneva, Switzerland. The conference—*NiCad94*— was organized by the International Cadmium Association with the cooperation and support of Eurobat. Four of the 27 papers presented discussed large-scale field testing of electric vehicles in Europe. Another eight dealt with the collection and recycling of spent batteries in both Europe and North America.

The nickel-cadmium, nickel-metal hydride, lithium-ion, and improved lead-acid electrochemical systems are in strong competition with one another for the portable rechargeable battery market. Improvements are continually being made to each of the systems. Energy density, cycle life, charge retention, shelf life, and performance at extreme temperatures are all being enhanced. These enhancements are being carried over into the emerging electric vehicle battery market—a market some analysts believe will be worth

$300 million by the year 2000.

France, Germany, Japan, and the United States continue to be the principal manufacturers and users of Ni-Cd batteries. However, tremendous strides have been made by competitors in China and Hong Kong since 1990. China now has nine Ni-Cd battery manufacturing operations. Another four Chinese suppliers produce Ni-Cd batteries as a sideline of their zinc-manganese dry cell operations.[19]

In France, the La Rochelle electric vehicle experiment is now in its sixth year of testing. The tests are a joint project of the city of La Rochelle, the automobile manufacturer PSA Peugeot Citroën, and the electric utility Electricité de France (EDF). Fifty electric vehicles (EV's) are currently operating in the city. Forty-six of the 50 EV's are powered by Ni-Cd systems; 4 by lead-acid.[20]

German automobile manufacturers have been conducting similar field tests in Zurich, Switzerland, and on the island of Rügen in the Baltic Sea. The 4-year project began in 1992 and is run by Deutsche Automobilgesellschaft mbH (DAUG) with the support of the German Federal Ministry for Research and Technology. Of the 59 vehicles being tested, 23 have sealed Ni-Cd batteries developed by DAUG. The DAUG battery minimizes gas pressures within the cell by using split negative, cadmium electrodes. Because of the unique electrode design, oxygen evolution is automatically controlled. The near-zero gas pressure allows the battery to be sealed and made maintenance-free. DAUG and Accumulatorenwerke HOPPECKE have formed a joint venture to manufacture the advanced Ni-Cd battery.[21]

The U.S. Department of Agriculture has been investigating a variety of plant species that preferentially concentrate mobile cadmium, nickel, and zinc from the soil by selectively absorbing the metals through their roots. A large part of the research was conducted at the Beltsville Agricultural Center in Maryland. Some of the work also was carried out by coinvestigators at Sheffield University and the University of Maryland. The team of scientists are trying to develop hybrids of these natural "hyperaccumulators" that have enhanced concentrating abilities. The hybrids would be planted across large tracts of land that have been contaminated with heavy metals and cannot be fully utilized in the present condition. The hyperaccumulators would be harvested over several growing seasons and ashed to produce a heavy metal concentrate.[22] Recent advances in genetic engineering have renewed interest in this idea of biological mining/land remediation.

In 1993, the International Agency for Research on Cancer reviewed a number of studies on the toxicological, carcinogenic, and mutagenic effects of cadmium as part of a much broader evaluation of carcinogenic risks in different occupational settings. The results of the evaluation were published in a monograph together with detailed background information on cadmium. The monograph pulls together the views and expert opinions of an IARC working group that met in Lyon, France, on February 9-16, 1993.

The working group concluded that cadmium and cadmium compounds are carcinogenic to humans. Most of the occupational exposure comes from airborne dust and fume. One of the principal hygienic concerns is the generation of cadmium oxide fumes at high temperatures, and the subsequent deposition and absorption of the oxide in the lungs. Exposure to such fumes is generally associated with the refining process (i.e., operations of roasters, calciners, kilns, and retorts.) Because of recent improvements in occupational hygiene, cadmium levels of 5 to 50 µg/m$^3$ of air can now be achieved at most of these facilities.

Other sources of potential high exposure include plants involved in battery manufacturing, pigment manufacturing, production of stabilizers such as cadmium stearate for PVC, or cadmium alloying of copper or silver. Special precautions also need to be taken when soldering cadmium-containing alloys or welding cadmium-coated surfaces. The separate engineering control air limits (SECALs) established by the OSHA Cadmium Standard for various industrial operations are shown in table 8 of the 1993 Cadmium Annual Review.

## Outlook

The outlook for cadmium is directly related to environmental and health concerns about the metal and its compounds. The domestic cadmium industry already has taken a number of steps to minimize occupational exposure and significantly reduce any adverse effects on the environment. Cadmium emissions from most processing and downstream manufacturing operations have been lowered to extremely safe levels. Many producers and first-use consumers have upgraded their facilities and are able to fully meet the new Federal standards. Most cadmium product manufacturers operating in borderline situations feel that the new OSHA SECALs will give them the time they need to achieve the desired PEL of 5 µg/m$^3$.

The principal problem facing the industry today is the safe and economic disposal of spent cadmium products. The cadmium industry believes that recycling programs are the most effective way to minimize the risks to public health and the environment, and is working hard to develop new recycling technology. To date, most of the work has concentrated on the processing of spent batteries, EAF dust, alloys, and electroplating sludges. The Rechargeable Battery Recycling Association has been working with a broad spectrum of manufacturers, retailers, and government agencies to improve Ni-Cd battery recycling rates and expects to have recycling networks operating in 17 States by the end of 1997. Even the cadmium pigments contained in some plastic scrap are being considered as secondary feedstocks because of rising disposal costs and increasing regulatory pressures. Disposal costs already exceed the price for virgin metal and are rapidly reaching a point where they will equal or exceed the cost of recovering the cadmium in most major waste streams.

The market for Ni-Cd batteries is expected to grow significantly over the next 5 years even if the Ni-Cd chemistry is not adopted for electric vehicles. Ni-Cd batteries will still be used in rechargeable power tools, home appliances, and other household equipment because of cost constraints. The markets for battery-powered cellular telephones, camcorders, personal computers, and related electronic equipment are all surging. Many of the newest satellites and commercial aircraft are using advanced Ni-Cd's for secondary power sources. In general, Ni-Cd batteries have a greater service life than several competitors and are less likely to be damaged by accidental overcharging.

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TABLE 1
SALIENT CADMIUM STATISTICS 1/

(Metric tons, cadmium content, unless otherwise specified)

| | 1990 | 1991 | 1992 | 1993 | 1994 |
|---|---|---|---|---|---|
| United States: | | | | | |
| Production of metal 2/ | 1,680 | 1,680 | 1,620 | 1,090 | 1,010 |
| Shipments of metal by producers 3/ | 1,860 | 1,740 | 2,080 | 1,320 r/ | 1,290 |
| Exports of metal, alloys, and scrap 4/ | 698 | 448 | 213 | 38 | 1,450 |
| Imports for consumption, metal | 1,740 | 2,040 | 1,960 | 1,420 | 1,110 |
| Stocks of metal, Government, yearend | 2,870 | 2,870 | 2,870 | 2,690 | 2,480 |
| Apparent consumption | 2,800 r/ | 3,080 r/ | 3,330 r/ | 2,940 r/ | 1,020 |
| Price, average per pound, New York dealer 5/ | $3.38 | $2.01 | $0.91 | $0.45 | $1.13 |
| World: Refinery production | 20,200 r/ | 20,900 r/ | 19,900 r/ | 18,900 r/ | 18,100 e/ |

e/ Estimated. r/ Revised.
1/ Previously published and 1994 data are rounded by the U.S. Bureau of Mines to three significant digits, except prices.
2/ Primary and secondary cadmium metal. Includes equivalent metal content of cadmium sponge used directly in production of compounds.
3/ Includes metal consumed at producer plants.
4/ New series of Harmonized Tariff Schedule codes.
5/ Price for 1 to 5 short-ton lots of metal having a minimum purity of 99.95%.

TABLE 2
U.S. PRODUCTION OF CADMIUM COMPOUNDS 1/

(Metric tons, cadmium content)

| Year | Cadmium sulfide 2/ | Other cadmium compounds 3/ |
|---|---|---|
| 1993 | 303 r/ | 731 |
| 1994 | 342 | 980 |

r/ Revised.
1/ Previously published and 1994 data are rounded by the U.S. Bureau of Mines to three significant digits.
2/ Includes cadmium lithopone and cadmium sulfoselenide.
3/ Includes oxide and plating salts (acetate, carbonate, nitrate, sulfate, etc.)

TABLE 3
SUPPLY AND APPARENT CONSUMPTION OF CADMIUM 1/

(Metric tons)

| | 1993 | 1994 |
|---|---|---|
| Industry stocks, Jan. 1 | 868 | 582 r/ |
| Production | 1,090 | 1,010 |
| Imports for consumption, metal | 1,420 | 1,110 |
| Shipments from Government stockpile excesses | 185 | 209 |
| Total supply | 3,560 r/ | 2,910 |
| Exports, metal 2/ | 38 | 1,450 |
| Industry stocks, Dec. 31 | 582 r/ | 439 |
| Consumption, apparent 3/ | 2,940 r/ | 1,020 |

r/ Revised.
1/ Previously published and 1994 data are rounded by the U.S. Bureau of Mines to three significant digits; may not add to totals shown.
2/ New series of Harmonized Tariff Schedule codes.
3/ Total supply minus exports and yearend stocks. Excludes shipments from Government stockpile excesses.

TABLE 4
INDUSTRY STOCKS, DECEMBER 31 1/

(Metric tons)

| | 1993 | | 1994 | |
|---|---|---|---|---|
| | Cadmium metal | Cadmium in compounds | Cadmium metal | Cadmium in compounds |
| Metal producers | 220 r/ | W | 55 | W |
| Compound manufacturers | 67 r/ | 282 r/ | 72 | 299 |
| Distributors | 13 | (2/) | 12 | (2/) |
| Total | 299 r/ | 282 r/ | 139 | 299 |

r/ Revised. W Withheld to avoid disclosing company proprietary data; included with "Compound manufacturers."
1/ Previously published and 1994 data are rounded by the U.S. Bureau of Mines to three significant digits; may not add to totals shown.
2/ Less than 1/2 unit.

TABLE 5
U.S. EXPORTS OF CADMIUM PRODUCTS, BY COUNTRY 1/

| Country | 1993 | | 1994 | |
|---|---|---|---|---|
| | Quantity (kilograms) | Value | Quantity (kilograms) | Value |
| Cadmium metal: 2/ | | | | |
| Argentina | 14 | 6,090 | -- | -- |
| Australia | 112 | 4,550 | -- | -- |
| Canada | 14,800 | 131,000 | 23,400 | 213,000 |
| China | -- | -- | 361,000 | 363,000 |
| France | 2,920 | 25,500 | 170,000 | 83,700 |
| Germany | 402 | 28,300 | 42,400 | 632,000 |
| Hong Kong | 635 | 5,000 | 725,000 | 662,000 |
| India | 300 | 7,350 | 77,700 | 76,900 |
| Israel | 1,910 | 12,000 | 547 | 14,100 |
| Italy | 408 | 7,560 | -- | -- |
| Japan | 4,250 | 99,900 | 4,210 | 217,000 |
| Korea, Republic of | -- | -- | 523 | 6,440 |
| Mexico | 4,790 | 29,900 | 39,400 | 216,000 |
| Netherlands | -- | -- | 179 | 12,100 |
| New Zealand | -- | -- | 2,880 | 271,000 |
| Panama | 1,390 | 12,300 | -- | -- |
| Singapore | 479 | 2,990 | -- | -- |
| Taiwan | 1,640 | 13,100 | -- | -- |
| United Kingdom | 4,000 | 85,500 | 165 | 6,710 |
| Total | 38,000 | 471,000 | 1,450,000 | 2,770,000 |
| Cadmium sulfide: (gross weight) | | | | |
| Canada | 24,000 | 13,500 | 107,000 | 56,500 |
| Japan | 6 | 8,620 | 38,800 | 8,000 |
| Korea, Republic of | -- | -- | 44,000 | 43,700 |
| Other | 7,440 | 7,650 | 15,100 | 11,200 |
| Total | 31,400 | 29,800 | 205,000 | 119,000 |

1/ Previously published and 1994 data are rounded by the U.S. Bureau of Mines to three significant digits; may not add to totals shown.
2/ Includes exports of cadmium in alloys, dross, flue dust, residues, and scrap.

Source: Bureau of the Census.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF CADMIUM PRODUCTS, BY COUNTRY 1/

| Country | 1993 | | 1994 | |
|---|---|---|---|---|
| | Quantity (kilograms) | Value | Quantity (kilograms) | Value |
| Cadmium metal: | | | | |
| Australia | 2,000 | $1,920 | 27,000 | $74,700 |
| Belgium | 178,000 | 215,000 | 232,000 | 496,000 |
| Bulgaria | 35,000 | 86,400 | 40,700 | 76,700 |
| Canada | 614,000 | 643,000 | 591,000 | 1,150,000 |
| China | 22 | 1,870 | 24 | 12,500 |
| Finland | 14,000 | 49,300 | 6,000 | 9,970 |
| France | 15,000 | 11,600 | 5,100 | 7,600 |
| Germany | 51,400 | 95,600 | 118,000 | 71,800 |
| Japan | 7 | 9,190 | 681 | 22,200 |
| Mexico | 332,000 | 261,000 | 17,800 | 76,800 |
| Netherlands | 17,100 | 11,600 | 25,000 | 94,000 |
| Norway | 59,600 | 53,400 | 34,500 | 60,900 |
| Peru | -- | -- | 10,000 | 16,500 |
| Russia | 76,800 | 220,000 | -- | -- |
| Spain | 19,500 | 18,300 | -- | -- |
| Sweden | 218 | 6,920 | -- | -- |
| Taiwan | 1,050 | 3,740 | -- | -- |
| Total 2/ | 1,410,000 | 1,690,000 | 1,110,000 | 2,170,000 |
| Cadmium sulfide: (gross weight) | | | | |
| Belgium | -- | -- | 3,600 | 42,600 |
| Canada | -- | -- | 2 | 5,380 |
| Japan | 1,230 | 30,200 | 28,100 | 83,500 |
| United Kingdom | 9,530 | 113,000 | 11,800 | 140,000 |
| Total | 10,800 | 143,000 | 43,500 | 272,000 |

1/ Previously published and 1994 data are rounded by the U.S. Bureau of Mines to three significant digits; may not add to totals shown.

2/ The 1994 total includes 5,000 kilograms of metal imported from France, valued at $6,280, that were removed from a bonded warehouse. General imports and imports for consumption were the same in 1993.

Source: Bureau of the Census.

TABLE 7

CADMIUM: WORLD REFINERY PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons)

| Country | 1990 | | 1991 | | 1992 | | 1993 | | 1994 e/ | |
|---|---|---|---|---|---|---|---|---|---|---|
| Algeria | 65 | | 78 | | 75 | e/ | 75 | e/ | 75 | |
| Argentina | 55 | | 49 | | 37 | | 34 | r/ e/ | 35 | |
| Australia | 638 | | 1,080 | | 1,000 | | 951 | r/ | 910 | 3/ |
| Austria | 44 | | 19 | | -- | | -- | | -- | |
| Belgium | 1,960 | | 1,810 | | 1,550 | | 1,570 | r/ | 1,560 | 3/ |
| Brazil e/ | 200 | | 200 | | 200 | | 200 | | 200 | |
| Bulgaria | 309 | | 232 | | 194 | r/ | 266 | r/ | 180 | |
| Canada | 1,470 | | 1,830 | | 1,960 | | 1,890 | r/ | 2,130 | 3/ |
| China e/ | 1,100 | | 1,200 | | 1,150 | r/ | 1,160 | r/ | 1,150 | |
| Finland | 569 | | 593 | | 590 | | 785 | r/ | 548 | 3/ |
| France | 187 | | 271 | | 252 | r/ | 137 | r/ | 140 | |
| Germany: | | | | | | | | | | |
| Eastern states | 17 | | XX | | XX | | XX | | XX | |
| Western states | 973 | | XX | | XX | | XX | | XX | |
| Total | 990 | | 1,050 | r/ | 941 | | 1,060 | | 1,120 | |
| India | 277 | | 271 | r/ | 313 | r/ | 255 | r/ | 201 | 3/ |
| Italy | 691 | | 658 | | 742 | | 517 | r/ | 659 | 3/ |
| Japan | 2,450 | | 2,890 | | 2,990 | | 2,830 | r/ | 2,630 | 3/ |
| Kazakhstan e/ | XX | | XX | | 1,000 | | 1,000 | | 1,000 | |
| Korea, North e/ | 100 | | 100 | | 100 | | 100 | | 100 | |
| Korea, Republic of e/ | 750 | r/ | 750 | r/ | 750 | r/ | 815 | r/ | 800 | |
| Macedonia e/ | XX | | XX | | 110 | | 100 | | 100 | |
| Mexico | 882 | | 688 | | 602 | | 797 | | 646 | 3/ |
| Namibia | 69 | | 67 | | 33 | | 13 | r/ | 23 | 3/ |
| Netherlands | 590 | | 549 | | 594 | | 526 | | 300 | |
| Norway | 286 | | 227 | | 247 | | 213 | r/ | 288 | 3/ |
| Peru | 265 | | 138 | r/ | 149 | r/ | 157 | r/ | 160 | |
| Poland | 373 | | 364 | | 132 | r/ | 150 | r/ e/ | 150 | |
| Romania e/ | 40 | | 10 | | 10 | | 10 | | -- | |
| Russia e/ | XX | | XX | | 800 | | 700 | | 500 | |
| Serbia and Montenegro | XX | | XX | | 8 | r/ | 6 | r/ | 3 | |
| South Africa, Republic of 4/ | 57 | r/ | 103 | r/ | 60 | r/ | 70 | r/ e/ | 65 | |
| Spain | 355 | | 344 | r/ | 329 | r/ | 340 | r/ e/ | 350 | |
| Thailand | -- | | 373 | | 635 | | 449 | r/ | 500 | |
| Turkey | 46 | | 22 | | 23 | | 31 | r/ | 22 | |
| U.S.S.R. e/ 5/ | 2,800 | | 2,500 | | XX | | XX | | XX | |
| Ukraine e/ | XX | | XX | | 200 | | 120 | r/ | 90 | |
| United Kingdom 6/ | 438 | | 449 | | 383 | | 458 | r/ | 470 | 3/ |
| United States 6/ | 1,680 | | 1,680 | | 1,620 | | 1,090 | | 1,010 | 3/ |
| Yugoslavia 7/ | 362 | | 250 | r/ e/ | XX | | XX | | XX | |
| Zaire | 127 | | 65 | | 84 | | 12 | r/ | 1 | |
| Total | 20,200 | r/ | 20,900 | r/ | 19,900 | r/ | 18,900 | | 18,100 | |

e/ Estimated. r/ Revised. XX Not applicable.

1/ Previously published and 1994 data are rounded by the U.S. Bureau of Mines to three significant digits; may not add to totals shown.

2/ This table gives unwrought production from ores, concentrates, flue dusts, and other materials of both domestic and imported origin. Sources generally do not indicate if secondary metal (recovered from scrap) is included or not; where known, this has been indicated by a footnote. Data derived in part from World Metal Statistics (published by World Bureau of Metal Statistics, Ware, the United Kingdom) and from Metal Statistics (published by Metallgesellschaft AG, Frankfurt, am Main, Germany, and World Bureau of Metal Statistics, Ware, the United Kingdom). Cadmium is found in ores, concentrates, and/or flue dusts in several other countries, but these materials are exported for treatment elsewhere to recover cadmium metal; therefore, such output is not reported in this table to avoid double counting. This table includes data available through Aug. 16, 1995.

3/ Reported figure.

4/ Cadmium content of cadmium cake.

5/ Dissolved in Dec. 1991.

6/ Includes secondary.

7/ Dissolved in Apr. 1992.